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Ecological approach for the evaluation of intelligence energy features in a building's skin

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Abstract

The recent development of 'intelligent' features and techniques for buildings' skins are intended to meet certain energy targets. These targets are rarely looked at in an integral way. Research in this area aims to reduce energy consumption as a consequence of using certain intelligent features. The importance of such features in a wider environmental scope is often ignored. This paper attempts to set criteria based on the energy flow principles in integral natural systems to evaluate the energy performance in an intelligent skin and relates to a certain definition of 'intelligence' in buildings' skins, drawing a list of features that can reflect this definition. A list of 23 carefully chosen buildings has been prepared as case studies to check the developed criteria. Different weights for different criterion are calculated for various features based on the ecological energy principles. The conclusion refers to the variations in adopting certain intelligent features in different parts of the world. © 1999 Elsevier Science Ltd. All rights reserved.

1. Efforts to evaluate the intelligent skin

A large number of research studies have recently revolved around the evaluation of the 'intelligent buildings' (e.g. Sala [13], Kroner [10]). Boyd and Jankovic [3] discussed a range of evaluation techniques of Post Occupancy Evaluation, Total Building Performance by ABSIC, BREEAM, and Environmental Impact Analysis. Boyd and Jankovic [3] attempted to derive evaluation criteria for intelligent

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buildings based on human IQ. The rating factors are divided into four categories: individual user needs, organisation/owner needs, and local and global environmental needs. The method is too ambitious regarding the large number of factors that interact in a building as a whole. Boyd [2] has reviewed the progress of intelligent buildings and derived a definition of building intelligence based on the performance of buildings. Boyd [2] drew similarities between building intelligence and organisation structure and performance. Boyd's performance criteria stressed the importance of interaction of five factors: efficiency; quality; control; image and flexibility. Harris and Wigginton [6] also emphasised the importance of controls and their ability to communicate with each other in an intelligent building.

Less attention was given to the evaluation of the performance of the skin. The main reason is the difficulty in evaluating a building's skin without the performance of its building as a whole. The definition of the skin boundaries is not yet clear. It is debatable whether intelligent buildings can save energy. Matsunawa and Nohara [11] claimed that many intelligent buildings use a lot of energy. Battle and McCarthy [1] derived criteria for evaluating the performance of a facade as a climate moderator. The factors include the regulation of energy flow, collection of free available energy, distribution of energy where required, storage and dissipation of energy, and communication between in and out of building. Cohen et al. [4] provided a less deterministic view of intelligent skin and energy performance. The variables used in the PROBE projects include, use of mass and ventilation, simple but efficient controls, ensure adequate lighting, limit unrequired solar gains and attentive building management. The importance of human perception and human comfort is discussed by Boyd and Jankovic [3]. Cohen et al. [4] also naturalises the result of the PROBE project using a *comfort assessment* method. Similar projects, which are driven by industrial research institutions, are based on features that are believed to be energy efficient. Such studies do not develop indicators that are capable of evaluating sustainable energy use.

Such a wide range of evaluation techniques made it difficult to understand what is required from the intelligent skin. It is very difficult to develop a feature if you cannot assess its performance. Studies attempting to review the performance of intelligent skins usually end with setting a list of intelligent features for each building (Harris et al. [7]). The difficulty remains that focusing on active energy issues might lead to narrow understanding of what is required from an intelligent skin. This paper attempts to set criteria that are drawn from ecological principles of energy flow in natural systems. The development of such criteria could lead not only to a more comprehensive assessment of energy flows within the skin boundaries, but also to a better understanding of what intelligent features are still needed. New intelligent features and/or techniques should be oriented to meet such targets.

2. The intelligent skin: definition and features

Harris and Wigginton [6] identify more than 30 separate definitions of intelligence in relation to buildings. As this paper adopts an ecological approach,

the biological metaphor of 'intelligent skin' is used emphasising its affinity with the human epidermis. The term intelligent skin is defined here as 'a composition of construction elements confined to the outer, weather protecting zone of a building, which performs functions that can be individually or cumulatively adjusted to respond predictably to environmental variations' [7]. On the basis of this definition, certain developed features in the building industry are selected to reflect our understanding of intelligent skin. The selection also agrees with the understanding of intelligence described above for the work of Cohen et al. [4] and Boyd and Jankovic [3]. The selected intelligent features of the Building Management System (BMS) are:

1. Learning facility
2. Weather data
3. Responsive lights
4. Sun tracking facility
5. Occupant override
6. Self-energy generation
7. Night cooling
8. Solar water heating

3. Case studies

Twenty-three cases have been selected from analysis of more than 300 projects (Table 1). The selection does not reflect energy efficiency in such buildings, but mainly as a result of the definition adopted. Some excellent projects that might have been chosen were not completed at the time of study. It is not the aim of this paper to review the selection procedures and filtration used to choose the 23 projects, but uses such selection to test the developed evaluation method. The cases were randomly drawn from different parts of the world but were mainly British and German. This gives another dimension to the importance of adopting various features in certain climates and cultures. The selected intelligent features are traced in all cases and identified. Table 2 describes the existence of these features in different cases.

4. Ecological energy flow principles

All ecological systems have similar characteristics in their demand for energy to operate and their waste to be carried away. A useful way for urban ecological considerations to be examined is to undertake an analysis of the critical elements and their interdependencies. In this approach, energy has received considerable attention as an ultimate resource (e.g. Odum and Odum [12]).

In contrast to buildings which are controlled and developed by man, natural processes have continually maintained a high degree of stability. As energy is

Table 1
Identification of intelligent features in the case studies

	BMS	Learning facility	Weather data	Responsive lights	Sun tracking facility	Self generation	Occupant override	Night cooling	Solar water heating	Number of features	Total score	Location
Gilaxo Wellcome World HQ	1	0	0	1	0	1	0	0	0	3	10	B
The Environmental Building	1	0	1	1	1	1	1	0	0	7	23	B
Helicon	1	0	1	1	0	1	0	0	0	4	14	B
Ionica Building	1	1	1	1	0	1	0	1	0	6	18	B
Learning Resource Centre	1	1	1	1	0	1	0	1	0	6	18	B
School of Engineering	1	0	1	1	0	1	1	1	0	6	20	B
Strathclyde Solar Residence	1	0	1	0	0	1	0	0	0	3	9	B
The Bruntland Centre	1	0	0	1	0	1	0	1	0	4	12	D
Villa Vision	1	0	0	0	0	1	1	0	1	4	12	D
Commerzbank HQ	1	0	1	1	0	1	0	1	0	5	16	G
Stadtor (City Gate)	1	0	1	0	0	1	0	1	0	4	11	G
HQ of Goiz	1	1	1	1	1	1	1	1	1	9	28	G
Heliotrop	1	0	1	0	1	1	1	1	1	7	21	G
Business Promotion Centre	1	0	1	0	0	1	1	0	0	4	13	G
Solar House	1	0	0	0	0	1	1	0	1	4	12	G
Design Office for Gartner	0	1	0	1	1	1	0	0	0	4	12	G
The Green Building	1	0	1	0	0	0	1	1	1	5	15	I
TRON-Concept Intelligent House	1	0	1	1	0	1	0	0	0	4	14	J
Super Energy Conservation Building	1	0	0	1	0	0	1	1	1	5	16	J
Tax Office Extension	1	0	0	1	0	1	0	1	0	4	12	N
SUVA Insurance Company	1	0	1	1	0	1	1	1	1	7	23	S
Phoenix Central Library	1	0	0	0	1	0	0	0	0	2	5	US
Occidental Chemical Centre	1	0	0	1	1	0	0	0	0	4	13	US

Table 2
Relationship between ecological energy principles and selected intelligent features

	BMS	Learning facility	Weather data	Responsive lights	Sun tracking facility	Occupant override	Night cooling	Solar water heating
Variety of energy resources	0	0	0	0	1	0	0	1
Negative feedback (recycling)	0	1	0	0	0	0	1	0
Reduction of energy output	1	1	0	1	0	0	1	0
Economic incentives	1	0	1	1	0	0	1	1
A steady state	0	0	1	0	1	0	1	0
Integration of sub-systems	1	0	0	1	0	0	0	1
Lessons from traditional settlement	0	0	1	0	1	1	1	0
Diversity of energy resources	0	0	0	0	1	0	0	1
Human participation	1	1	0	0	0	1	0	0
Weight	4	3	3	3	4	2	5	4

transferred from one substance to another through various nutrient cycles, a high probability of operational success is achieved. As ecosystems illustrate the principles governing the flows of energy, the analogy will trace the reasons behind the stability of energy flows in ecosystems.

Three main principles of energy flows in ecosystems have been distinguished. These principles are driven from the laws of thermodynamics and applied by Odum and Odum [12] to the characteristics of natural environment.

4.1. Principle 1 — Law of conservation of energy:

The energy entering the system must be accounted for either as being stored or as flowing out. This view is mainly based on the first law of thermodynamics 'Energy is neither created nor destroyed'.

4.2. Principle 2 — Law of degradation of energy

In all processes some of the energy loses its ability to do work and is degraded in quality.

4.3. Principle 3 — Maximum power principle

The system that gets the most energy and uses it most efficiently survives in competition with other systems.

As Odum and Odum [12] gives a general biological view to those principles, it was decided to examine them here in conjunction with more specific ecological principles driven by Van Der Ryn [14] in applying the 'integral systems' in nature to man made 'Linear systems'. Van Der Ryn distinguished four processes unique to the integral systems of nature:

1. Integral systems process energy and material through closed loops of multiple channels.
2. Integral systems release energy in the system in small increments.
3. Integral systems maintain a steady state through negative feedback and permeable boundaries.
4. Integral systems store information in a decentralised genetic memory.

It was decided to examine the previous principles and to compare them with energy flow patterns in so called intelligent buildings' skins. The results of this investigation were as follows:

The first process of the ecosystem — processing energy through closed loops of multiple channels — emphasises the following steps to simulate these characteristics and adopt the integral design:

1. As natural systems maintain survival through energy cycles, it is important to recognise and analyse how structures are operating as energy systems in order to strengthen the weak point between different sub-systems.

2. While natural systems use a complex web of energy supply resources, urban structures are mainly dependent on fossil fuels to maintain human comfort. Thus, the city has a negative impact on environment — a lot of energy is potentially a lot of pollution. However, the control of the energy flow through outside walls will overcome and contain this problem.
3. There is a need to achieve better energy balances between input and output by increasing the diversity of passive and active energy controls.
4. A steady state is the climax of evolution processes in ecosystems and thus an ultimate goal for human settlements. Therefore, the idea of unlimited growth of energy consumption to maintain human comfort inside buildings must be re-evaluated.

The analysis of the second principle — releasing energy in small increments — shows that:

1. There is a need to design the components of buildings' skins not just to use minimum energy but, more importantly, to reduce energy output. Thus, the objective here is not to cut the supply of energy, but to design a system that could store this input efficiently and release as little energy as possible.
2. Social behaviour is an important constraint in the achievement of integral system. The individual's desires may conflict with the group welfare. Thus with the increasing depletion of natural resources, there is an increasing need to define the environmental property rights, such as solar access rights (Knowles [9]). There is also a need to develop a system of economic incentives in relation to resource utilisation. Without such incentives, architects and builders will continue to address the individual's desires rather than the group welfare.

Two main conclusions can be drawn from the discussion of the third principle — maintaining a steady state through negative feedback and permeable boundaries:

1. As the important relationships between the components of ecosystems are regulated by positive and negative feedback loops, heat gains in buildings which process positive feedback forces must also contain negative feedback processes. This involves passive measures in design such as appropriate cooling techniques if they are to remain stable. This point is also discussed in connection with the first principle.
2. Buildings have to be designed as integrated energy systems where the boundaries between these systems will be reduced. In other words, the interactions between all systems and components in the building have to work together rather than separately. Each component of the system will tend to perform overlapping functions. A tree, for example, has to work as a landscape, as a filter of dust and noise, and as an obstacle against undesired wind and incident solar energy on the neighbouring buildings. Davies and Rogers [5] explained the importance of multi-functionality of the wall as an energy system. The wall, he explained, should act as an absorber, radiator, reflector, filter, and transfer device.

The analysis of the fourth ecological principle — storing information in a decentralised genetic memory — emphasises the following points:

1. A traditional building design is a useful way to study how a self organised settlement, developed from trial and error, can be a good adaptable example to nature.
2. The success of any energy efficient building depends on storing information in a multi-cultural system. In other words, diversity in activities and networks must be achieved in order to have a stable system.
3. The aim of conservation is not to constrain and reduce energy consumption but to use it efficiently. Diversity, for example, may require more energy to be developed in order to maintain the system. An example is the solar cells which need large energy input but will result in a long term energy efficiency.

In order to provide criteria from the previous discussions, the following items are chosen to reflect the main principles of energy flow in ecosystems:

1. variety of energy resources;
2. negative feedback through recycling of energy and materials;
3. reduction of energy output;
4. economic incentives for environmental behaviour;
5. a steady state as a main objective;
6. levels of integration of different systems;
7. lessons from traditional settlements;
8. degree of diversity in energy systems;
9. feedback from human participation.

These criteria will examine the characteristics of outside walls in order to provide theoretical guidelines.

4.4. Investigation and analysis of case studies

A priority matrix is created by assigning different weight to the selected intelligent features in buildings' skin. The selected intelligent features in Section 2 are examined with the identified ecological energy principles in order to assess the priorities of these features. Table 2 demonstrates how the weighting criteria are developed and shows also that night cooling is a feature that reflects many ecological energy principles while occupant override received the least score. Economic incentives on the other hand have been highly considered in most of the selected intelligent features. This is not surprising, as economic dimension of energy consumption was on top of priorities in developing these features. Varieties of energy resources and recycling principles are not well reflected in the intelligent features. This might explain the tendency in new projects to address these two particular principles. The Solar Offices of Doxford International in the north east of England [8] and Debis Headquarters in Berlin are such examples.

Case studies showed a strong relationship between the location of the building and the types of features used. Figs. 1 and 2 show the differences between the

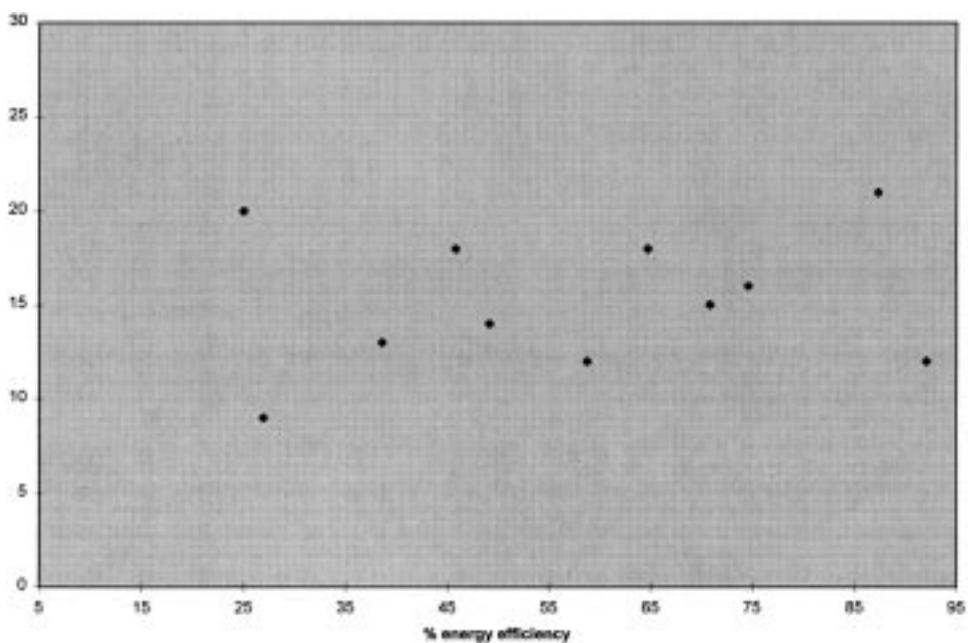


Fig. 1. Relation between energy efficiency and scores given.

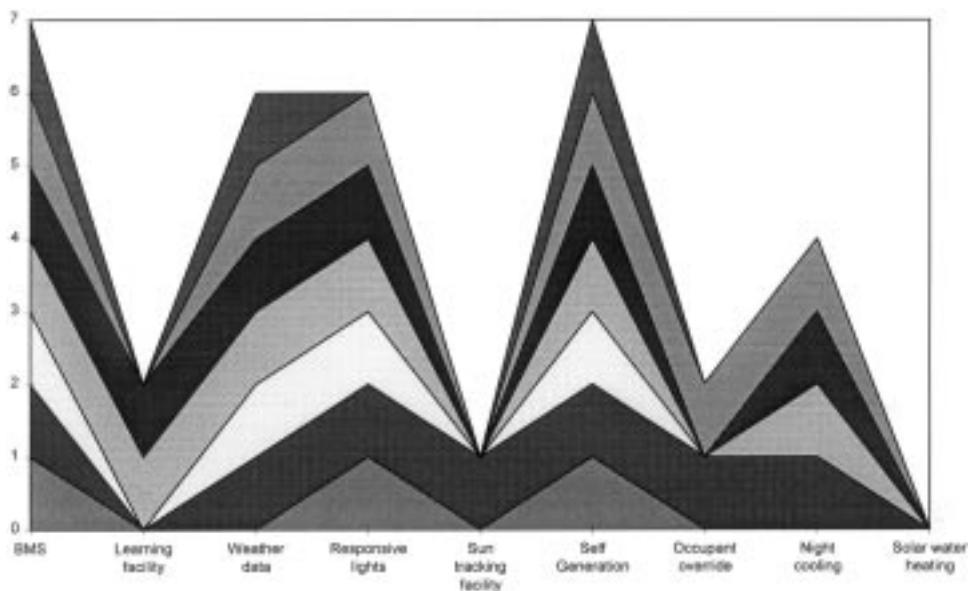


Fig. 2. Intelligent features in British cases.

British and German cases. While the British cases were less interested in sun tracking facilities and solar water heating, German cases were less interested in using features for responsive lighting. These differences can also be compared to the total number of cases from round the world in Fig. 3.

Energy efficiencies of the selected cases were calculated based on data collected from the case studies about the actual annual energy consumption and the typical energy consumption in similar buildings. Fig. 4 shows that there is an expected weak correlation between the score given and the claimed energy efficiency. This paper argues that this is the result of emphasis of the features to reduce energy consumption with no wider environmental considerations. Fig. 5 shows that most of the cases were given total scores in the mid range of 12–18 points. This shows that the selected features do raise the issues related to some ecological energy principles, but need more understanding to address others.

Fig. 6 shows that there is a relationship between scores given and the number of features identified in different cases.

6. Conclusion

It is difficult to evaluate the performance of energy efficient features in intelligent skins of buildings. It is important to develop evaluation criteria that take into account a wider environmental scope than that of reduction of active energy consumption. Analysis of the chosen case studies shows variations in

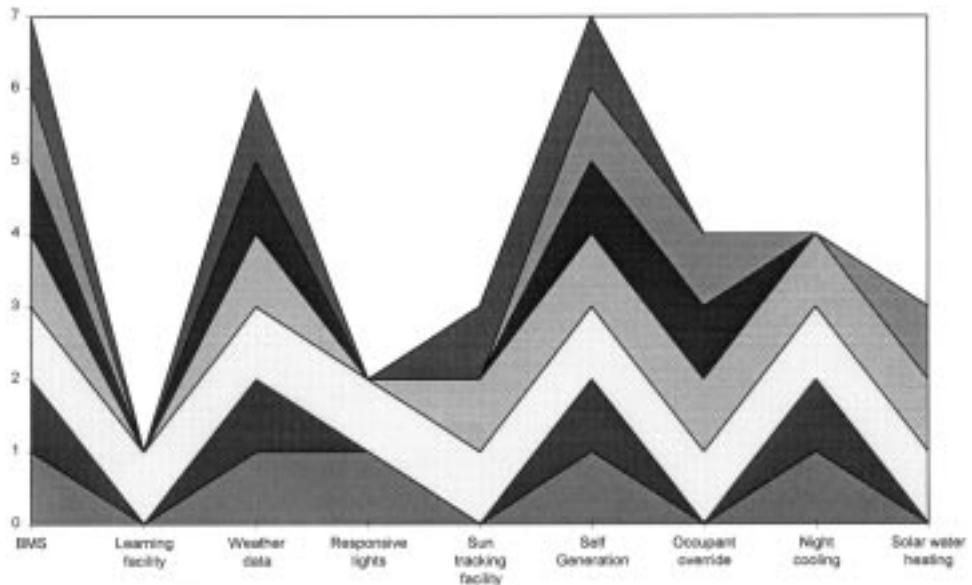


Fig. 3. Intelligent features in German cases.

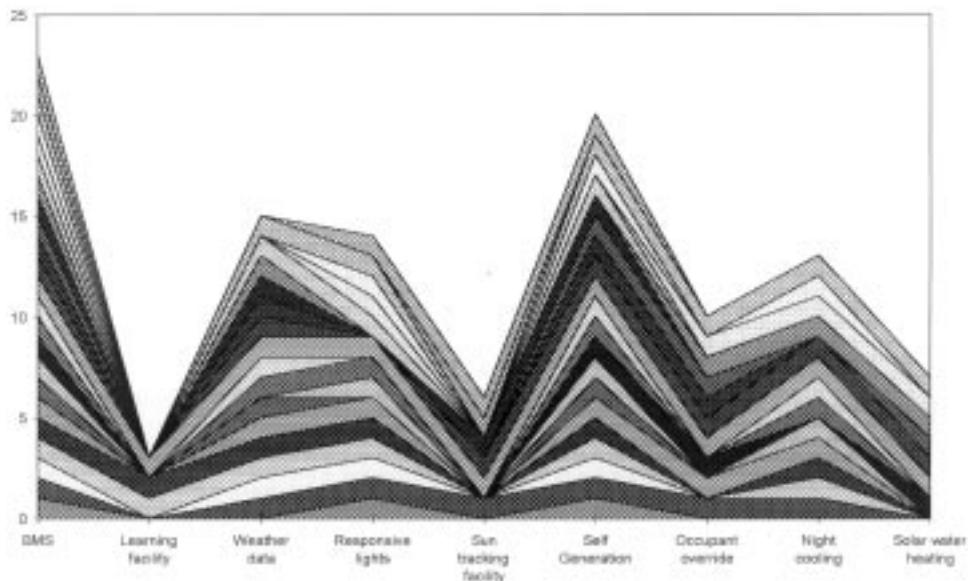


Fig. 4. Intelligent features in the world's cases.

applying existing energy efficient technology in different parts of the world. Some of these differences are related to climatic conditions but mostly to economic incentives of these particular countries. An ecological approach is, therefore, able

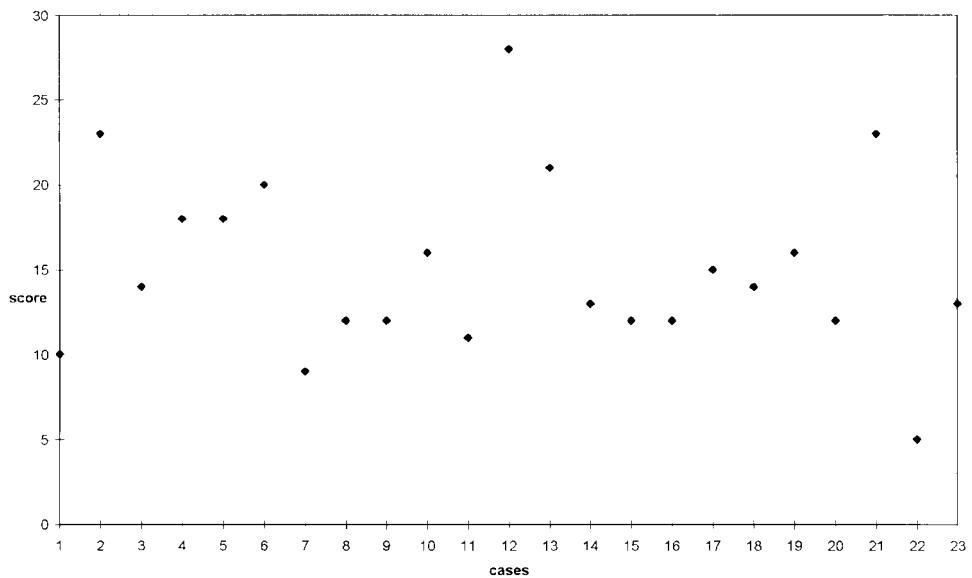


Fig. 5. Scores of all case studies.

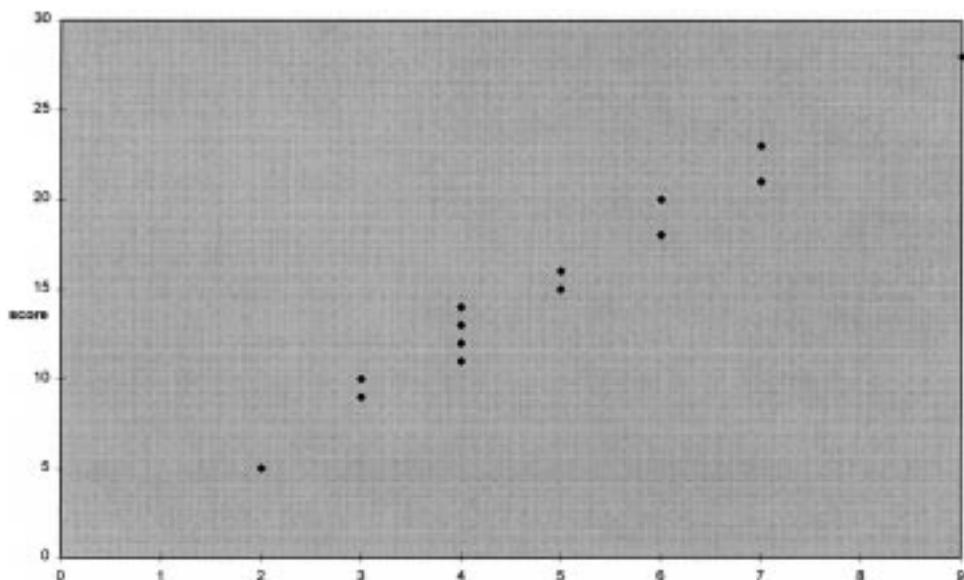


Fig. 6. Relationship between intelligent features and score given.

to provide a neutral basis for assessment of these features. It is still early to decide whether some of the features with low weight (Table 2) can be considered a recessed gene in the evolution of an intelligent skin. There is a need to look into these features within an ecological view to improve their energy performance. Other features which received high weight, such as learning facility, are not yet fully applied or appreciated within the construction industry. This paper demonstrates that ecological energy principles can provide useful bases for the evaluation of the performance of energy efficient features. The understanding of these bases can also guide the development of a new generation of energy efficient integrated components of the future intelligent skin.

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